

Effects of Noise and Tonal Stimuli on Hearing in Pinnipeds

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LONG-TERM GOALS

The long-term goals of this effort are to assess the effects of tonal and broadband noise exposures on aerial and underwater hearing in three representative species of pinniped: the California sea lion (*Zalophus californianus*), the harbor seal (*Phoca vitulina*), and the northern elephant seal (*Mirounga angustirostris*). Specifically, the goals are to model the onset, growth, and recovery of noise-induced temporary threshold shift (TTS) with respect to the duration, amplitude, and energy of the noise exposure and to opportunistically explore the relationship between temporary and permanent auditory threshold shifts.

OBJECTIVES

The practical objective for FY08 was to complete behavioral testing with three subjects against an equal energy matrix of tonal noise exposures (with similar characteristics to mid-frequency sonar) based on pre-determined combinations of stimulus duration and received sound pressure level.

The specific aims were (1) to compare the characteristics of the threshold shifts induced by exposure to tonal sounds to the auditory effects induced by broadband noise exposure so that the effects of mid-frequency tonal noise could be incorporated into existing models of TTS for the amphibious pinnipeds, and (2) to evaluate differential auditory responses to waterborne versus airborne sound in order to determine whether the hearing losses incurred in one physical medium translate to equivalent losses the other.

APPROACH

Psychoacoustic measurements of hearing sensitivity in individual animals are obtained prior to and immediately following voluntary noise exposure in order to reveal transient noise-induced changes in hearing sensitivity. The noise exposures comprise a 4.1 kHz tonal fatiguing stimulus that is systematically varied in duration and level. Hearing is evaluated at the frequency of the noise exposure (4.1 kHz) and one-half octave higher (5.8 kHz). Hearing tests are primarily conducted under water, in a 7.5 m diameter, 2.5 m deep acoustically mapped saltwater tank. To ensure complete recovery of hearing following noise exposure, and to establish necessary baseline levels of hearing sensitivity, all subjects participate in regular audiometric testing across their entire frequency range of hearing, both

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under water and in air. Aerial testing occurs in a customized 3 x 5.6 x 2.5 m tall hemi-anechoic chamber that is adjacent to the animals' living space.

The subjects have extensive experience in psychoacoustic testing. They are trained for rapid measurement of hearing sensitivity in a controlled environment using positive reinforcement and operant conditioning technology. Auditory thresholds for 500 ms tonal sounds (frequency modulated signals with 10% modulation bandwidth) are obtained from each subject in 6-8 min using a modified psychophysical method of limits. Threshold shifts are calculated as the difference in hearing thresholds measured just before and just after noise exposure. Noise exposures are also performed under voluntary control, with the subjects diving to and waiting at a stationing device during transmission of the 4.1 kHz fatiguing stimulus until cued to resume audiometric testing at a nearby apparatus.

A small team of researchers and students at Long Marine Laboratory participate in the study. David Kastak was the original PI and project leader. He designed the experimental protocol and hardware configuration used for sound production and calibration, and the software used for aerial hearing assessment. Colleen Reichmuth manages research activities and animal care, and assumed PI responsibilities for the project in January 2008. Graduate students Jason Mulsow and Asila Ghoul conduct experimental sessions, train the animals for the data collection procedures, and assist in data analysis. The team is directly supported by an experienced crew of undergraduate volunteer research assistants. Ron Schusterman of UC Santa Cruz provides assistance with psychophysical testing methodologies and James Finneran of the US Navy Marine Mammal Program contributes occasional technical expertise and software development.

WORK COMPLETED

The harbor seal, the California sea lion, and the northern elephant seal were successfully trained for underwater threshold testing and noise exposure procedures. The harbor seal progressed systematically through the noise training phase of the experiment, which involved gradual titration of the noise upward from an energy level yielding no measureable threshold shift. The 4.1 kHz fatiguing noise was titrated from 12 to 60 sec, and the level of the noise was titrated from 120 to 184 dB re 1 μ Pa over a period of months in FY07. This training phase was designed for slow ramp up to the noise exposure conditions that would elicit moderate levels (10-20 dB) of TTS.

Due to an unexpected finding at the end of FY07 (see Results), the focus for FY08 was shifted to careful and repeated assessment of hearing sensitivity in the harbor seal, both in air and under water. Subsequent tonal noise exposures with all subjects were suspended according to the requirements of our animal care and use protocols, pending review of this data and further consultation with permit biologists at the NMFS Office of Protected Resources and the IACUC at the University of California Santa Cruz. The California sea lion and the northern elephant seal continued baseline audiometric testing during FY08.

RESULTS

The harbor seal showed little to no TTS at the frequency of the noise exposure (4.1 kHz) and one-half octave higher (5.8 kHz) as the sound exposure level was titrated from 131 to 202 dB re 1 μ Pa²s (Fig. 1). However, on the second exposure of the 202 dB re 1 μ Pa²s fatiguing stimulus (a 60 sec signal with a

sound pressure level of 184 dB re 1 μ Pa) the seal showed a threshold shift in excess of 48 dB. This result was not anticipated or predicted based on animal models of TTS generated from studies using broadband noise exposure, which show a characteristic pattern of TTS growth with increasing sound exposure level (Salvi and Boettcher, 2008; Kastak et al. 2007). The seal showed no detectable behavioral response to the presentation of the tonal stimulus during any of the noise exposures.

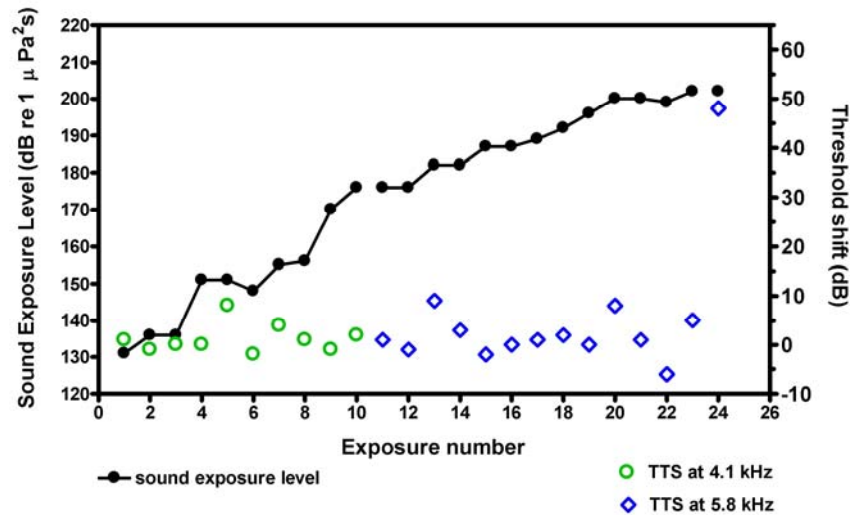


Figure 1. The amount of TTS observed in a harbor seal following exposure to a mid-frequency tonal fatiguing stimulus did not show a predictable increase with increasing noise energy prior to inducing a threshold shift greater than 48 dB at a sound exposure level of 202 dB re 1 μ Pa²s.

The unexpected occurrence of the large magnitude threshold shift during the training phase of the experiment provided an opportunity to track long-term recovery following a tonal noise exposure. Hearing sensitivity was measured at different frequencies and in different physical environments at regular intervals starting within 1 hr of the exposure event. Assessment of recovery has continued throughout FY08. The largest and most persistent effect occurred in the frequency range from one-half octave to one octave above the frequency of noise exposure. Recovery was tracked as function of log time following the exposure event. Full recovery of hearing at the frequency of noise exposure (4.1 kHz) occurred within 2 days. Hearing sensitivity a half-octave higher (5.8 kHz) has not fully recovered one year following the exposure event. The pattern of recovery observed is consistent with a three phase model of recovery from TTS (Salvi and Boettcher, 2008) showing an early phase during the first several hours where there is little recovery, a rapid recovery phase extending about five days, and finally a very slow recovery phase followed by a plateau (Fig. 2). The plateau of hearing sensitivity for this animal at present reflects and 8-10 dB elevation over baseline levels of hearing previously measured at 5.8 kHz; therefore, the result can be considered at least a persistent, if not a permanent, threshold shift (PTS).

The auditory effect of this noise exposure was also explored across the frequency range of hearing under water and the resultant audiogram shows a notch in sensitivity above 4.1 kHz, representing the frequency spread of the hearing loss. Hearing appears normal at 12.8 kHz and above, indicating that the majority of the loss occurs within the range of a half-octave to a full octave above the tonal noise exposure (Fig. 3). When hearing within this range was similarly tested in air, a corresponding loss of sensitivity was observed at 5.8 kHz and 8.2 kHz, relative to baseline hearing thresholds measured in

the same physical environment. This finding supports the hypothesis that—for amphibious mammals such as pinnipeds—temporary threshold shifts that are induced in one medium result in comparable hearing losses in the other, despite differences in absolute aerial and underwater hearing sensitivity.

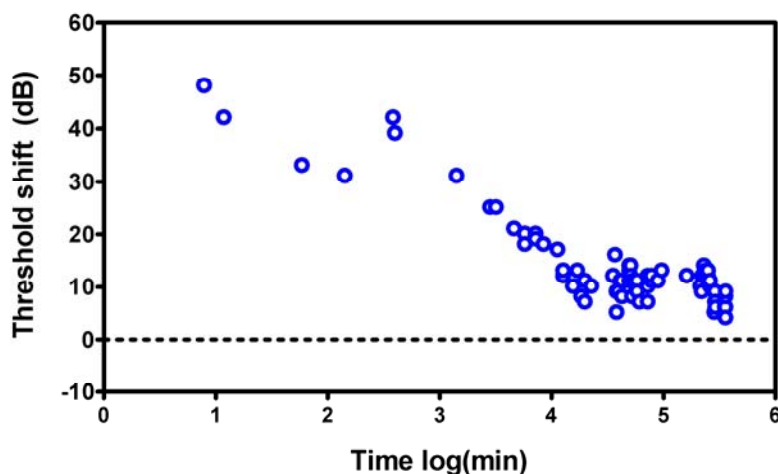


Figure 2. Long-term recovery of hearing sensitivity at 5.8 kHz in a harbor seal following a 48 dB threshold shift induced by a 4.1 kHz tonal noise exposure. The recovery data is shown with respect to time in log(min) and the dotted line represents the mean of baseline hearing thresholds obtained prior to the exposure event.

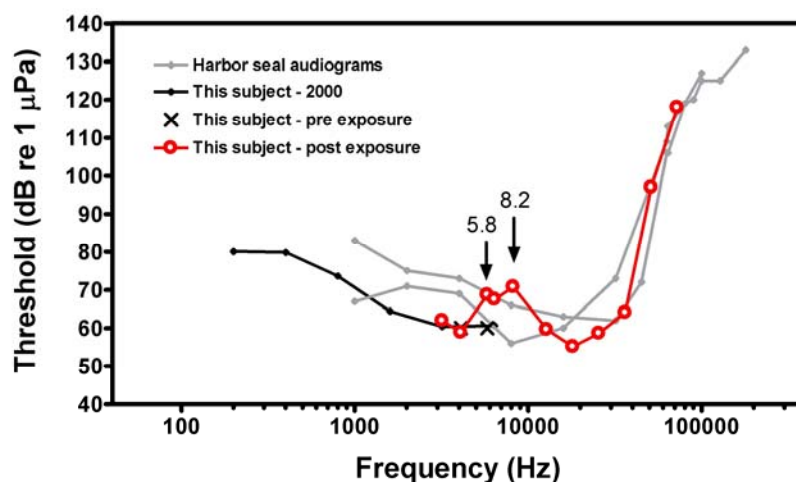


Figure 3. The underwater audiogram of the harbor seal following long-term recovery of the 48 dB threshold shift reveals an 8-10 dB notch in sensitivity that extends one-half to one octave (5.8 to 8.2 kHz) above the frequency of tonal noise exposure (4.1 kHz).

IMPACT/APPLICATIONS

The TTS data generated by this project and preceding projects have contributed to the first set of formal recommendations for noise exposure criteria developed specifically for free-ranging marine mammals, which in turn have been widely used by the operational Navy, industry, and U.S. and International regulators to establish appropriate guidelines and mitigation for anthropogenic noise emissions in marine environments.

The unanticipated results dealing with PTS generated by this project have also been presented expeditiously and directly to the scientific community at two international conferences in FY08. As this is the first evidence of permanent auditory damage caused by underwater tonal noise exposure, the findings will have definite implications relating to the use of mid-frequency sonars in coastal environments. The lack of measurable behavioral reaction or avoidance during this exposure event will necessitate reconsideration of anthropogenic noise mitigation measures relying solely on behavioral disturbance metrics.

RELATED PROJECTS

None

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PUBLICATIONS

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